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Improved Sidelobe Performance of Array Antennas with the Use of Overlapping Sub-Array Architecture

S.R. RENGARAJAN

Department of Electrical and Computer Engineering
California State University
Northridge, CA

J.B.L. RAO

Radar Analysis Branch
Radar Division

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S.R. Rengarajan* and J.B.L. Rao

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*Department of Electrical and Computer Engineering
California State University
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Array antennas with sub-array architecture are frequently employed in phased array systems. However, the sub-array architecture can introduce severe pattern degradation in the form of higher sidelobes that arise as the frequency is changed or when multiple beams are generated by combining outputs of sub-arrays with a digital beamformer. This report presents results of an investigation on the use of overlapping sub-arrays for improving the sidelobe performance.

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Improved Sidelobe Performance of Array Antennas with the Use of Overlapping Sub-Array Architecture

1. Introduction

Array antennas with sub-array architecture are commonly employed in phased array systems. In order to operate over wide instantaneous bandwidth, such arrays are time-delay steered with digital time delays introduced at the input of each sub-array. Elements in each sub-array contain phase shifters that are controlled such that each sub-array has the correct phase slope at the center frequency of the instantaneous operating bandwidth (for the central beam, if multiple beams are to be generated). There are three scenarios in which the sidelobe performance of the array becomes poor. 1) If elements of each sub-array have a uniform aperture distribution, and if the distribution of all the sub-arrays have the complex weights to produce the desired pattern, there may be a sidelobe degradation. This occurs when the grating lobes of the array factor (of sub-arrays) are multiplied by the broad pattern of each sub-array. 2) At the center frequency of a wide instantaneous bandwidth the desired antenna pattern may be synthesized. With the use of true-time delay steering, the array factor maintains a pattern shape at band edges but for a change in beamwidth. The pattern of each sub-array squints due to use of phase shifters. Therefore the overall pattern shows a loss in peak gain as well as degradation in sidelobes. 3) If multiple beams are to be formed in the receive mode by a digital beam former using complex weights at sub-array level, poor sidelobes result for outer beams if the phase shifts of each sub-array were set for the central beam. These three effects were discussed previously [1,2]. This document examines the use of overlapped sub-arrays for improving the sidelobe performance. All the computations assume a linear array of 64 elements with a half wavelength spacing at the center frequency. The array is divided into 8 equally spaced sub-arrays with 8 elements for each sub-array. The overlapping scheme will be discussed later. Time delay steering is employed at sub-array level and elements of each sub-array have phase shifters that are set at the center frequency for the central beam. Fig. 1a shows the geometry of the array for the non-overlapped architecture and Fig. 1b shows a partially overlapped architecture (only four elements per sub-array are shown for simplicity).

2. Analysis and discussion

2.1 Improved sidelobe performance for the broadside pattern

For convenient reference the pattern given in [1,2] is reproduced here in Fig. 2. We have the sub-array weights chosen for a 30-dB Dolph-Chebyshev pattern. Elements in each sub-array have a uniform distribution. The overall pattern is obtained by multiplication of array factor and the sub-array pattern. The grating lobes of the array factor contribute to relatively big sidelobe pairs with the highest one at about –25 dB. This problem is easily overcome by choosing non-uniform amplitude distribution for the elements of each sub-array. One could design the entire array distribution to correspond to that of Dolph-Chebyshev or Taylor for the desired sidelobe level. This makes sub-arrays non-identical and might increase the cost of a large array.

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2.2 Performance at edges of a wide instantaneous bandwidth

Mailloux [1] has given the patterns of the 64-element array that is time-delay steered to 45 degrees from broadside. The time-delays are applied at the sub-array levels with element phases set to maintain the correct phase slope at the center frequency. At a frequency 10% away from the center frequency the sidelobe level relative to the main beam peak is found to be at –7.55 dB. Fig. 3 is a reproduction of the corresponding plot given in [1]. Optimization of the sidelobe level as a function of complex weights of sub-array inputs will produce only a small improvement since the phases have to be fixed to maintain the beam peak at the desired location. Controlling the amplitudes alone without losing the peak gain will have only limited control. Some initial investigations using a genetic-algorithm optimization of sidelobe level as a function of sub-array weights showed that the improvement on the sidelobe level was only about a couple of dBs. These results are not included here.

Overlapping sub-array architecture is employed in limited scan array applications in which scanning is achieved at the sub-arrays level [1]. In order to suppress the grating lobes of the array factor produced by the distribution of sub-arrays, the pattern of elements in each sub-array should be nearly uniform within the limited scan region and should drop to a low level outside. This is basically a pulse-type pattern that requires a sin (x)/x (sinc) distribution. The pulse width has been chosen to have a value equal to one half of the spacing in u (= sin θ) space between adjacent grating lobes of the array factor. Truncating the infinite sinc distribution to a single sub-array is not adequate. Ideally we need to have a complete overlap, i.e., input to each sub-array is distributed to all elements on both sides with an amplitude distribution that samples a sinc function. However, such a system requires a rather complicated feed network. It has been implemented in linear arrays in reflectors and lenses [1]. Fig. 4 shows the patterns of the completely overlapped array and the patterns of the central sub-array and that of an edge sub-array. The pattern of the central sub-array is very close to the ideal pulse shape where as that of the edge sub-array deviates substantially due to severe effects produced by truncation at one end. Each of the two overlapped sub-array patterns is squinted towards the broadside since the frequency is 10% above the center frequency. Clearly we have improved the sidelobe level to well below –25 dB. Extension of this concept to planar arrays would make the feed network extremely complex and expensive.

Instead of complete overlap, we considered overlapping of only adjacent sub-arrays. This requires that input to each sub-array be distributed to its eight elements as well as eight elements in one sub-array on each side. However, each edge sub-array overlaps to only one adjacent sub-array. The patterns of the partially overlapped array and the central and edge sub-array are shown in Fig. 5. The side lobe level is only –21.2 dB. It is caused by the fact that the partially overlapped sub-array patterns have substantial deviation relative to the desired pulse shape because of the truncation of the sinc distribution. The results improve significantly when each sub-array overlaps to two adjacent sub-arrays. Fig. 6 shows a sidelobe level of –24.5 dB. The partially overlapped sub-array pattern is closer to the pulse shape in this case.

2.3 *Sidelobe level of outer beams of multiple beams*

In digital beam forming systems, multiple simultaneous receive beams are formed by choosing appropriate complex weights for each sub-array signal for a given beam channel. An array without overlap between sub-array element distributions was considered first. The sub-arrays have been time-delay steered to point the beam at 42.5^{o} from broadside. Element phases have been set so that each sub-array pattern points at 45^{o} from broadside. The computations were performed at the center frequency for an outer beam at 42.5^{o} (the central one at 45^{o}). The complete array pattern and that of a single sub-array are shown in Fig. 7. The array pattern shows a sidelobe level of about –15 dB. This is due to the fact that the grating lobes of the array factor have not been sufficiently suppressed by the pattern of a single sub-array. Fig. 8 shows the array pattern and the pattern of a single sub-array at a frequency 10% above the center frequency. All other parameters were the same as those for Fig. 7. The sidelobe level of the array pattern is severely degraded to –3.5 dB. This severe degradation in sidelobe level is caused by the combination of frequency shift and beam shift.

With the use of an overlapped architecture (each sub-array overlapping two adjacent ones) the sidelobe performance of the previous two cases improve significantly. These results are shown in Figs. 9 and 10 respectively. The sidelobe level in Fig. 9 is better than –26 dB whereas in Fig. 10 it is –12.6 dB. Clearly the latter figure is not adequate. At 10% above the center frequency, our computation showed that the sidelobe level of the overlapped array is below –25 dB for this outer beam (not shown). However, at this frequency an outer beam at 47.5^{o} will have a poor sidelobe level.

The effect of the pulse width of the synthesized pattern of each sub-array, on sidelobe performance of outer beams at $\pm$ 10% from the center frequency was studied. Previously we used a value of A, half the spacing (in $u = \sin\theta$ space) between adjacent grating lobes of the array factor (array of sub-arrays). A reduced value of 0.8 A was considered for the sub-array pattern width. In order to produce this pulse pattern we need a new sinc distribution to elements of overlapping sub-arrays. Fig. 11 shows the array pattern and sub-array patterns of the case considered in Fig. 10 with the new pulse width (0.8 A) of the sub-array pattern. Sidelobe level has been reduced to –22dB.

3. Conclusion

Our studies show that partially overlapped sub-array architecture has the potential to improve the sidelobe performance compared to the non-overlapped system. Further improvements may be possible by optimizing various parameters, including the complex weights of the sub-arrays.

References

[1] R. J. Mailloux, Phased Array Antenna Handbook, Artech House, Inc., Norwood, MA, 1994.

[2] J. Rao, Some Limitations of Sub-Array Architectures, NRL Viewgraphs.

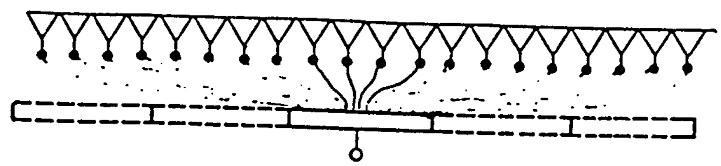


Fig. 1a A schematic view of an array of sub-arrays (no overlap)

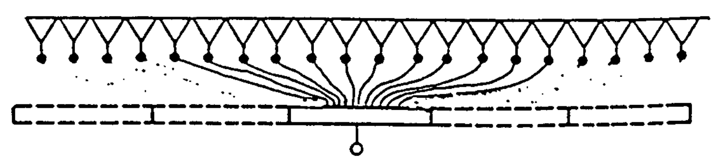
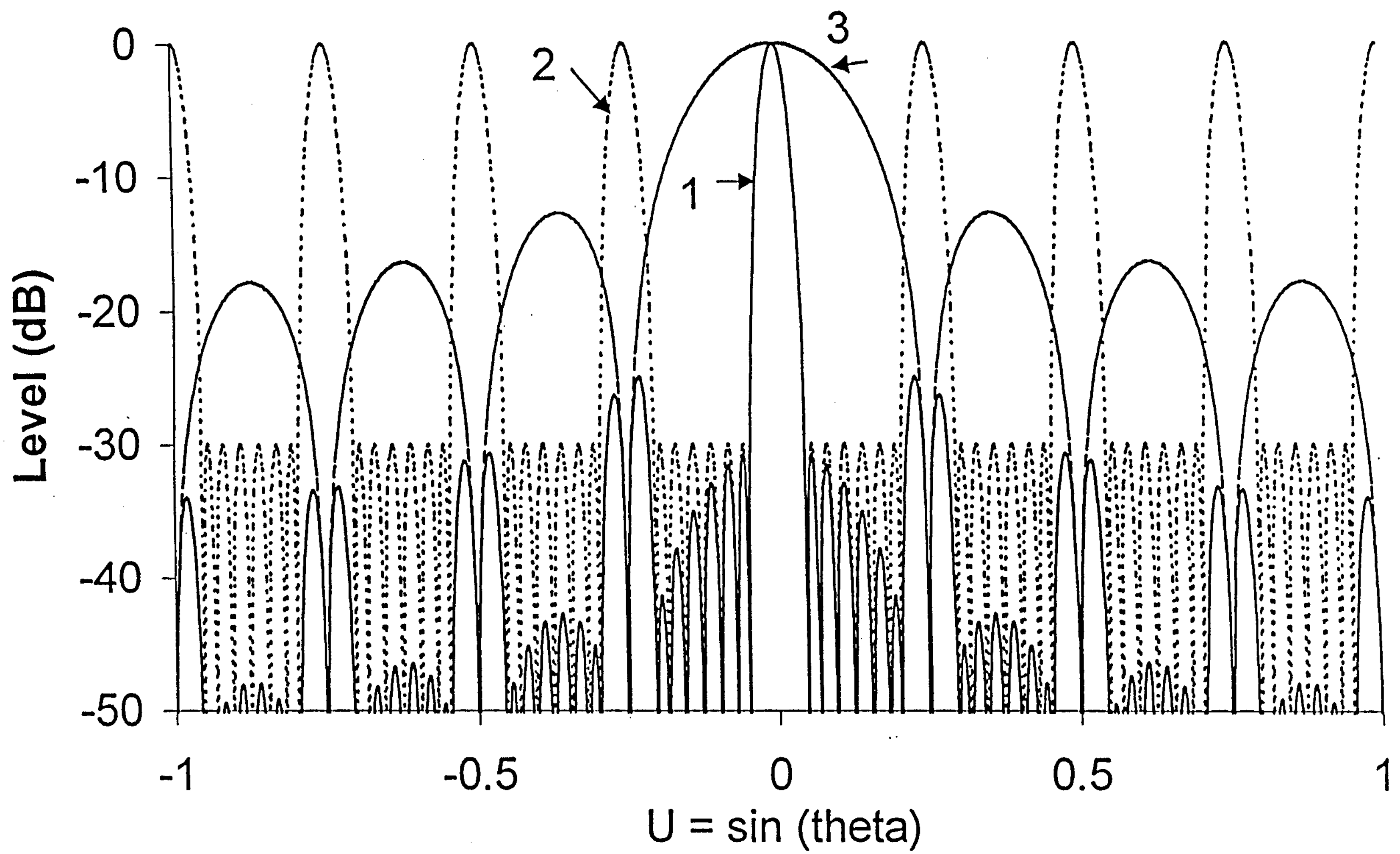


Fig. 1b A schematic view of an array of sub-arrays (one sub-array overlap)

Fig. 2 Pattern of an array of sub-arrays

1-array pattern, 2 - array factor, 3 - sub-array pattern



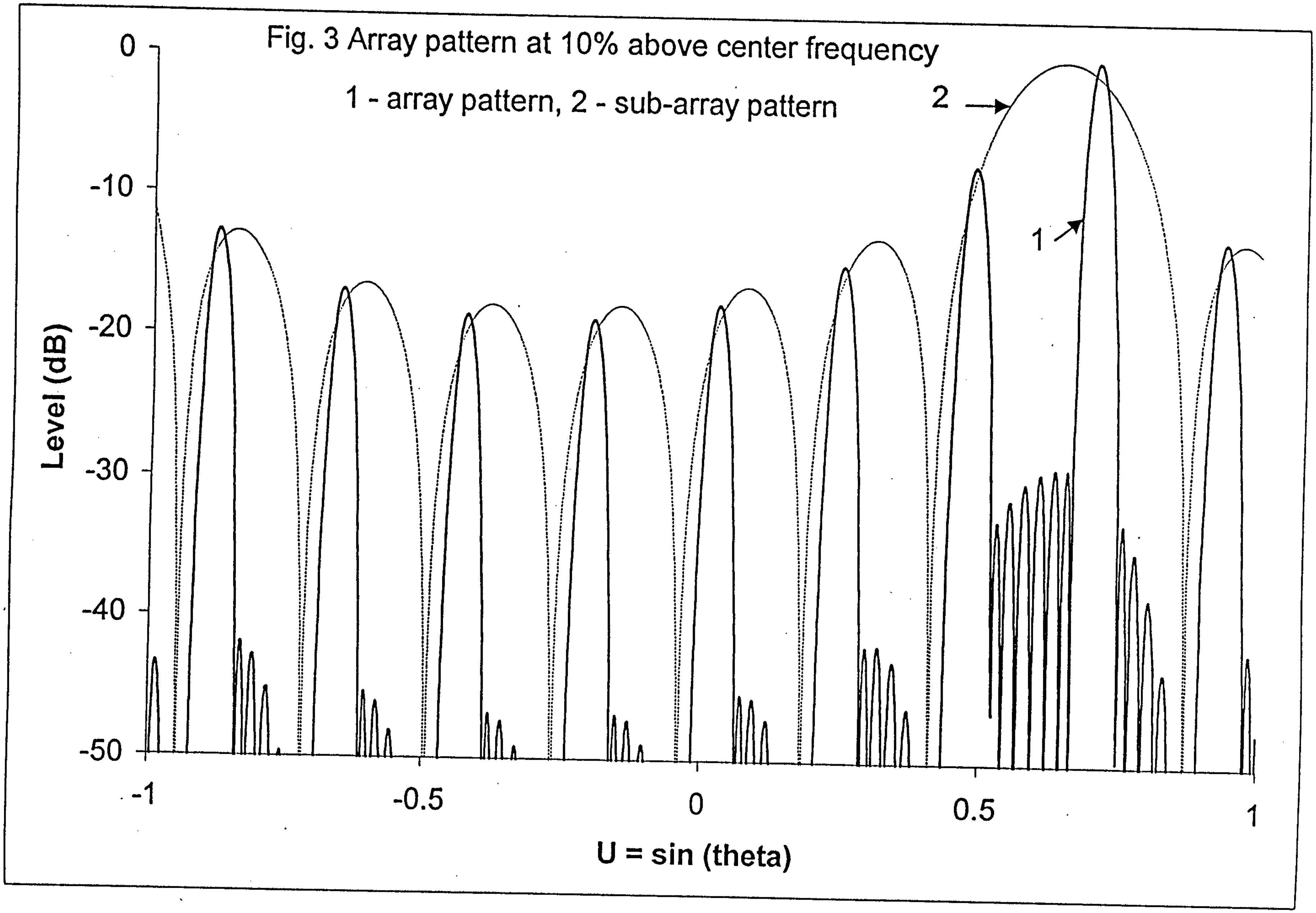


Fig. 3 Array pattern at 10% above center frequency
1 - array pattern, 2 - sub-array pattern
2
1
0
-10
-20
-30
-40
-50
Level (dB)
-1
-0.5
0
0.5
1
U = sin (theta)

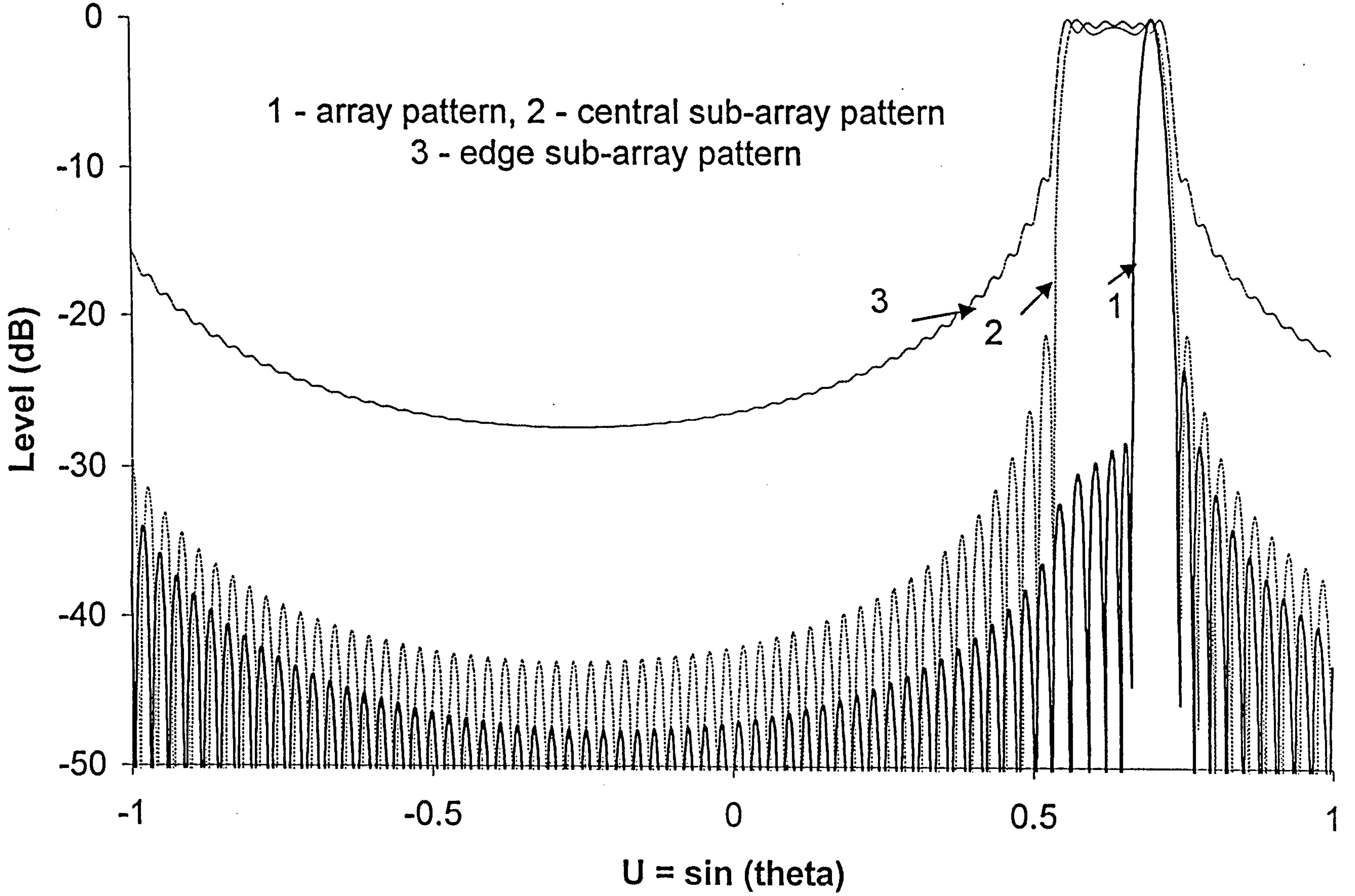
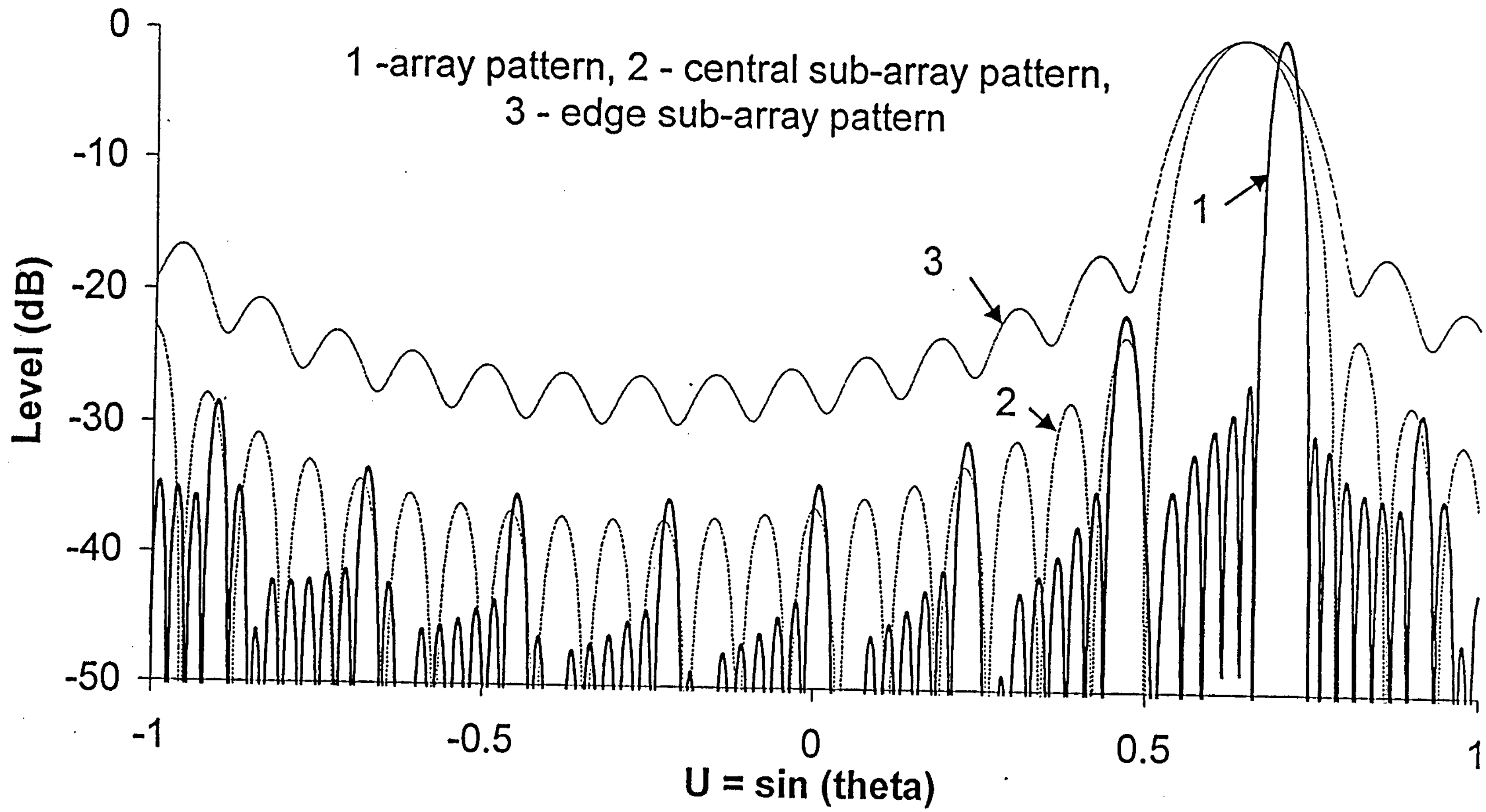


Fig. 4 Overlapped array pattern at 10% above center frequency

Fig. 5 Array pattern (one sub-array overlap),
10% above center frequency



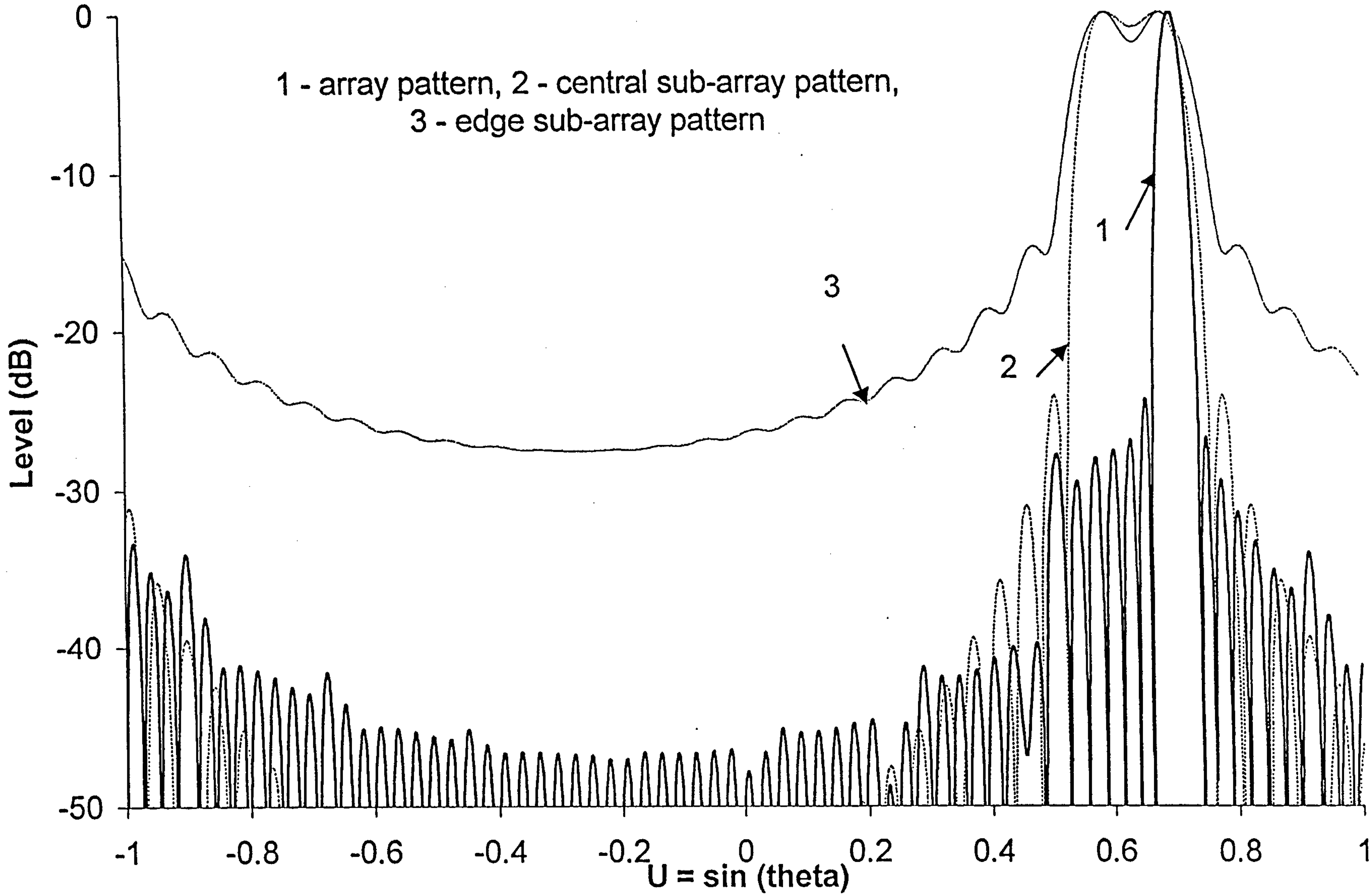


Fig. 6 Array pattern (two sub-array overlap) 10% above center frequency

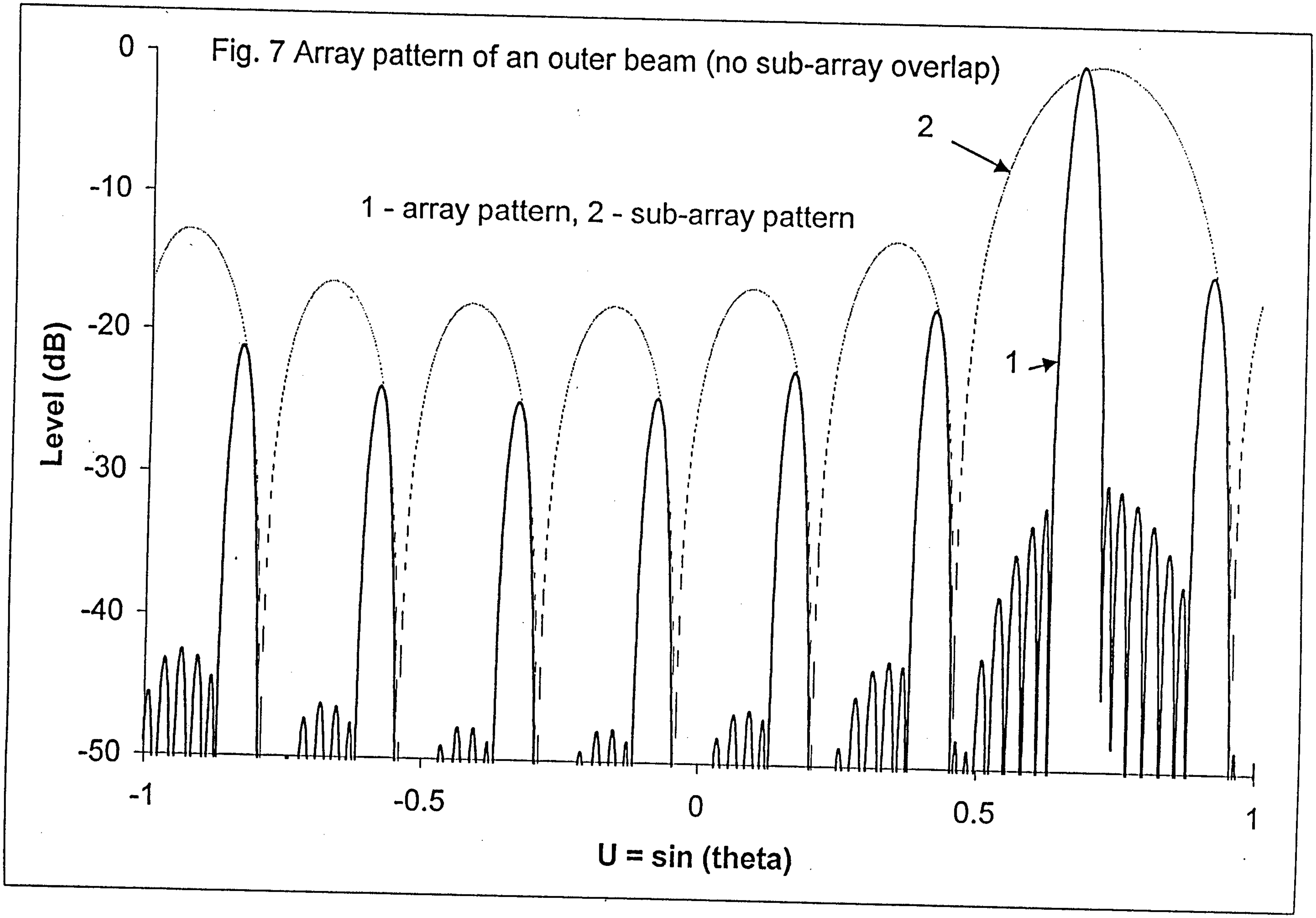


Fig. 7 Array pattern of an outer beam (no sub-array overlap)
1 - array pattern, 2 - sub-array pattern
2
1
Level (dB)
0
-10
-20
-30
-40
-50
-1
-0.5
0
0.5
1
U = sin (theta)

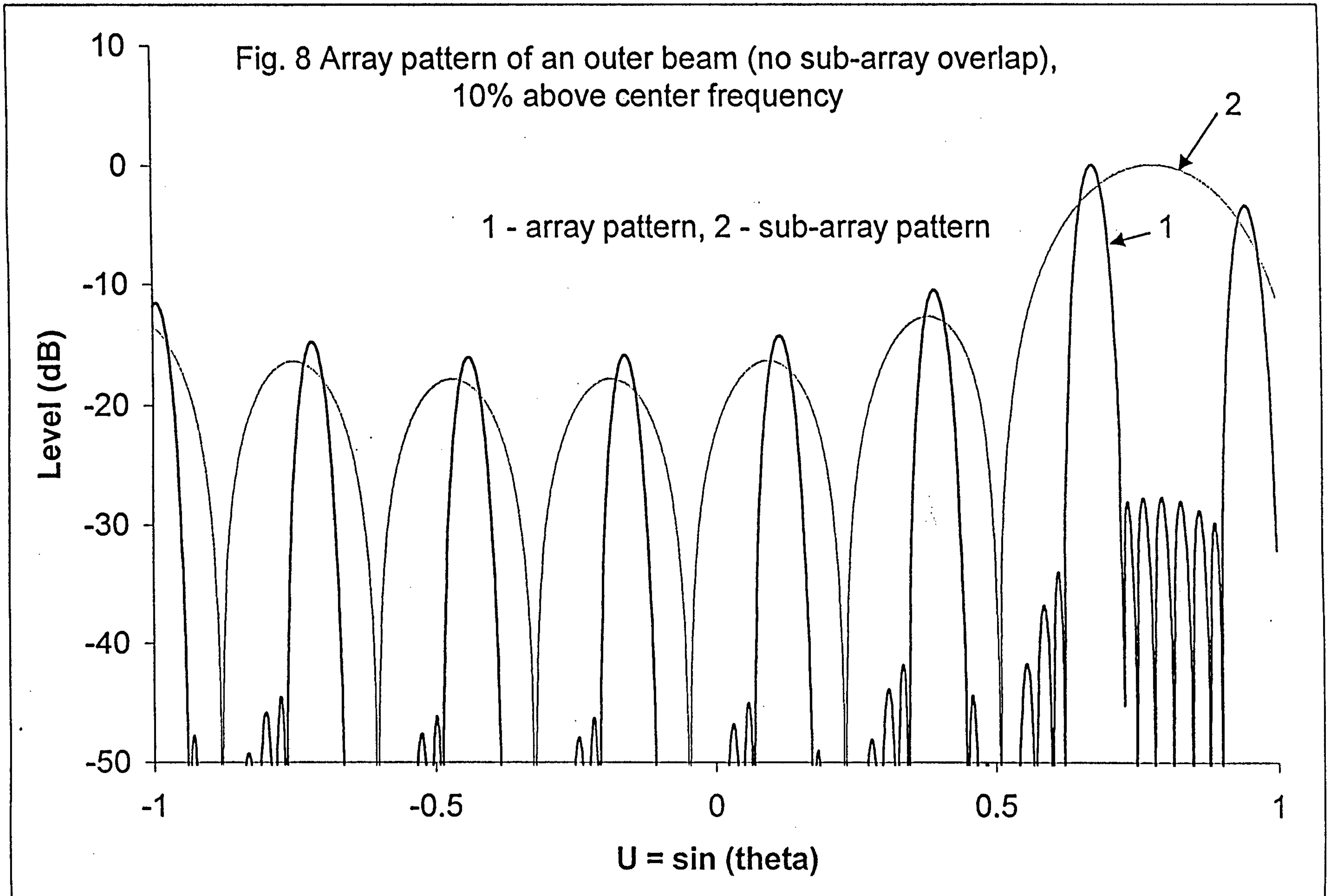


Fig. 8 Array pattern of an outer beam (no sub-array overlap),
10% above center frequency
1 - array pattern, 2 - sub-array pattern
1
2
Level (dB)
10
0
-10
-20
-30
-40
-50
-1
-0.5
0
0.5
1
U = sin (theta)

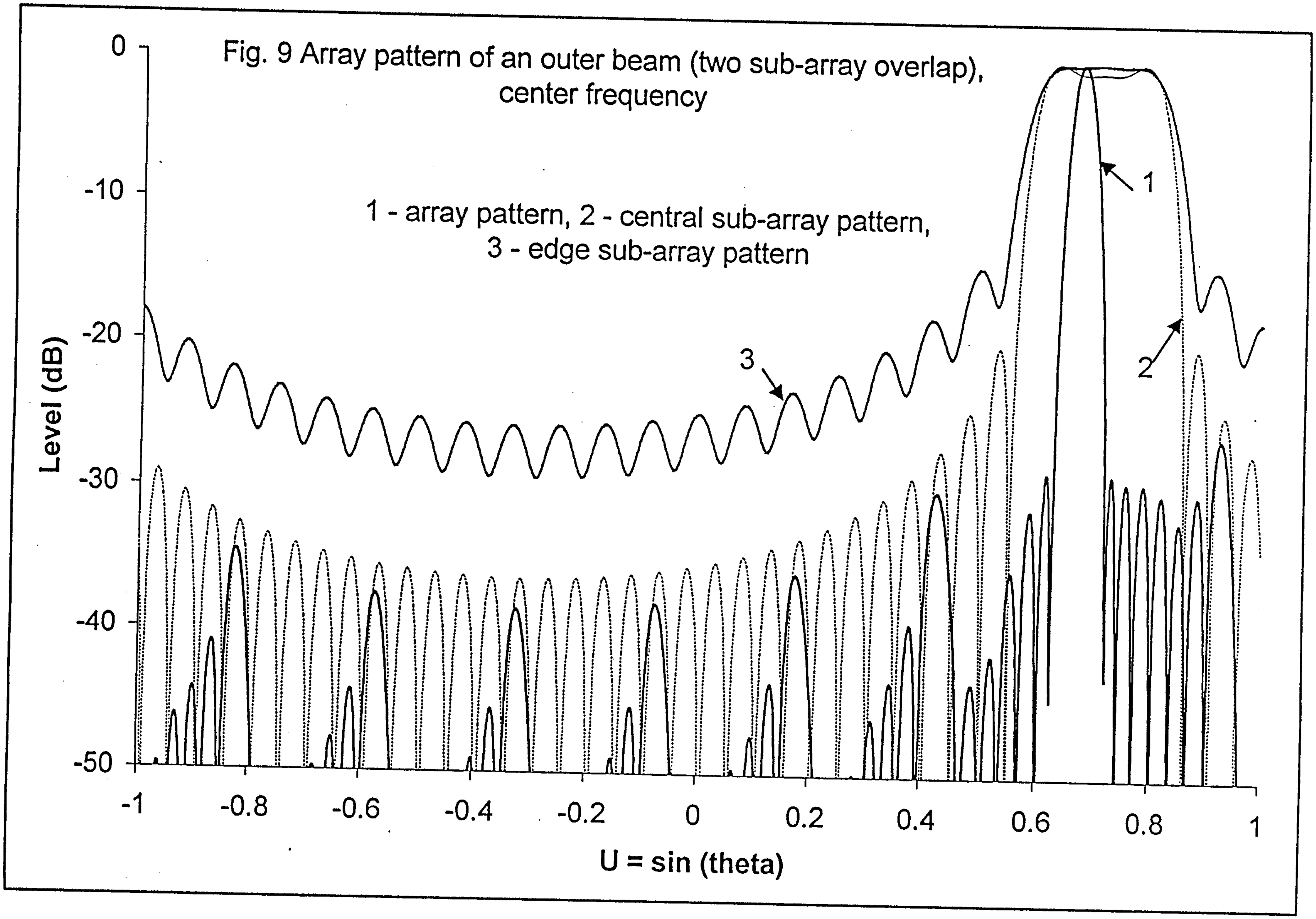
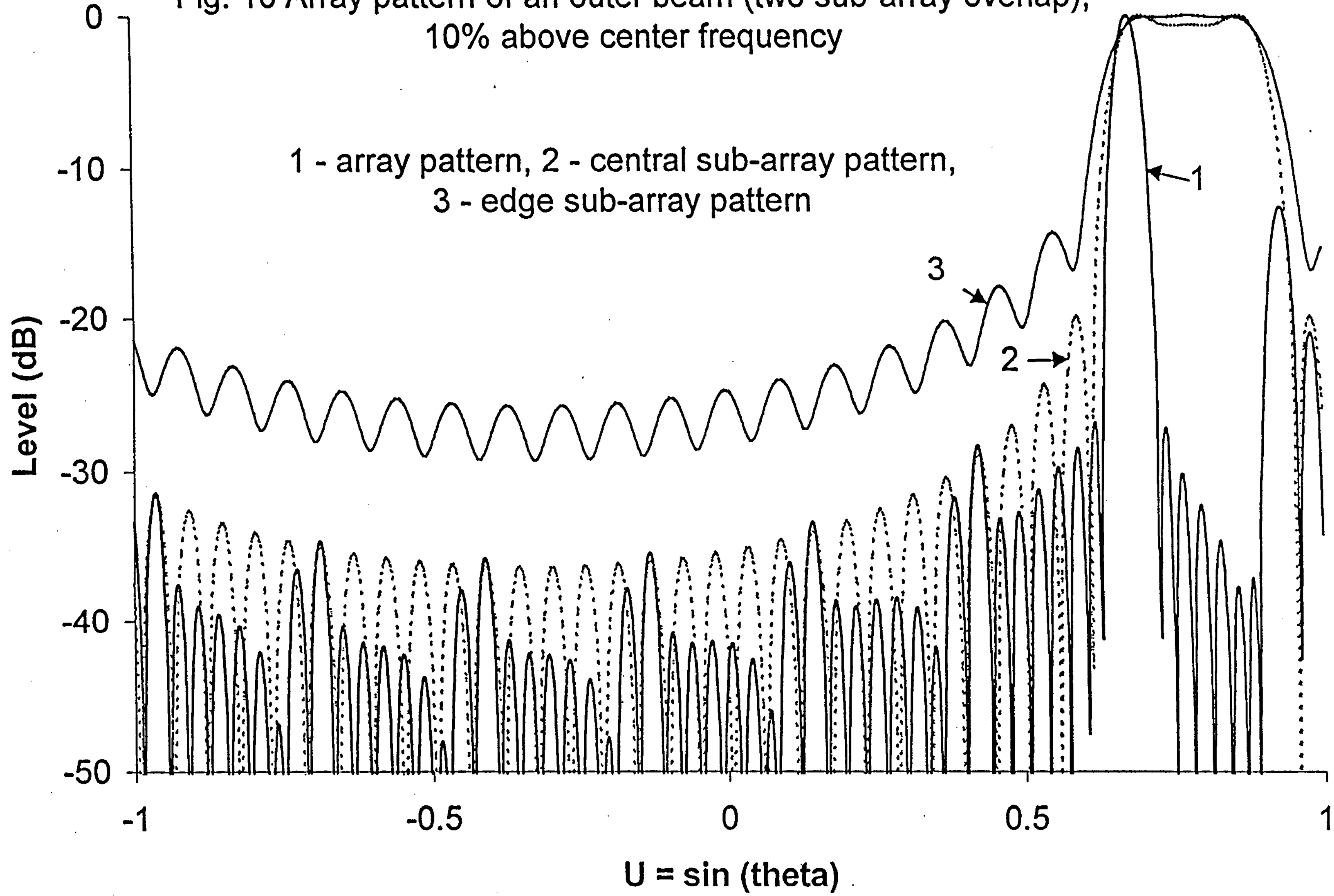


Fig. 9 Array pattern of an outer beam (two sub-array overlap), center frequency

Fig. 10 Array pattern of an outer beam (two sub-array overlap), 10% above center frequency



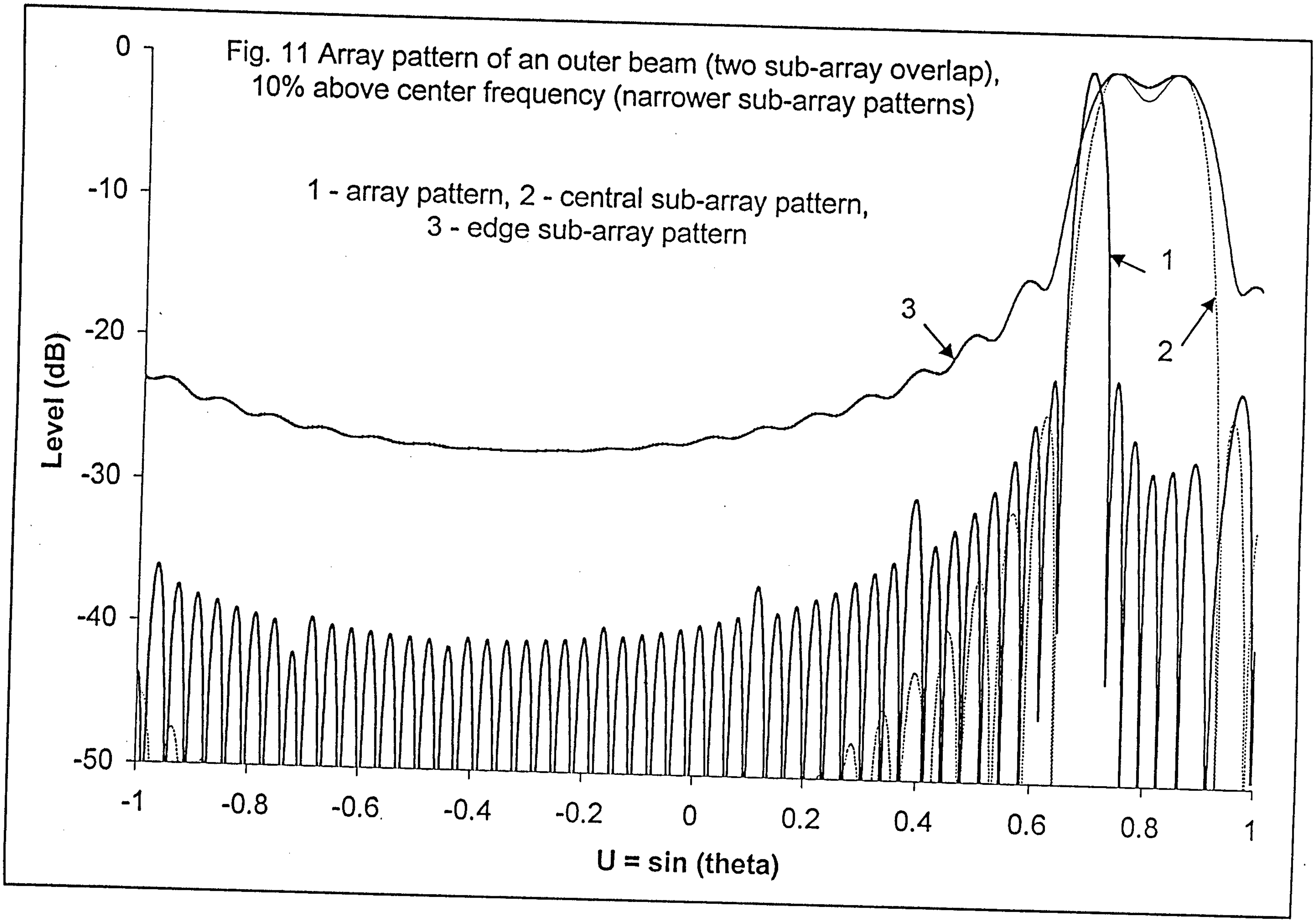


Fig. 11 Array pattern of an outer beam (two sub-array overlap), 10% above center frequency (narrower sub-array patterns)